Miscellaneous Paper CHL-98-7
October 1998

US Army Corps of Engineers
Waterways Experiment Station

Roll-On/Roll-Off Mooring Force Discharge Facility Test Results

by Robert C. Carver, Brenda J. Wright, Jimmy Fowler

WES

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Prepared for Headquarters, U.S. Army Corps of Engineers

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U.S. Army Corps of Engineers
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3909 Halls Ferry Road
Vicksburg, MS 39180-6199

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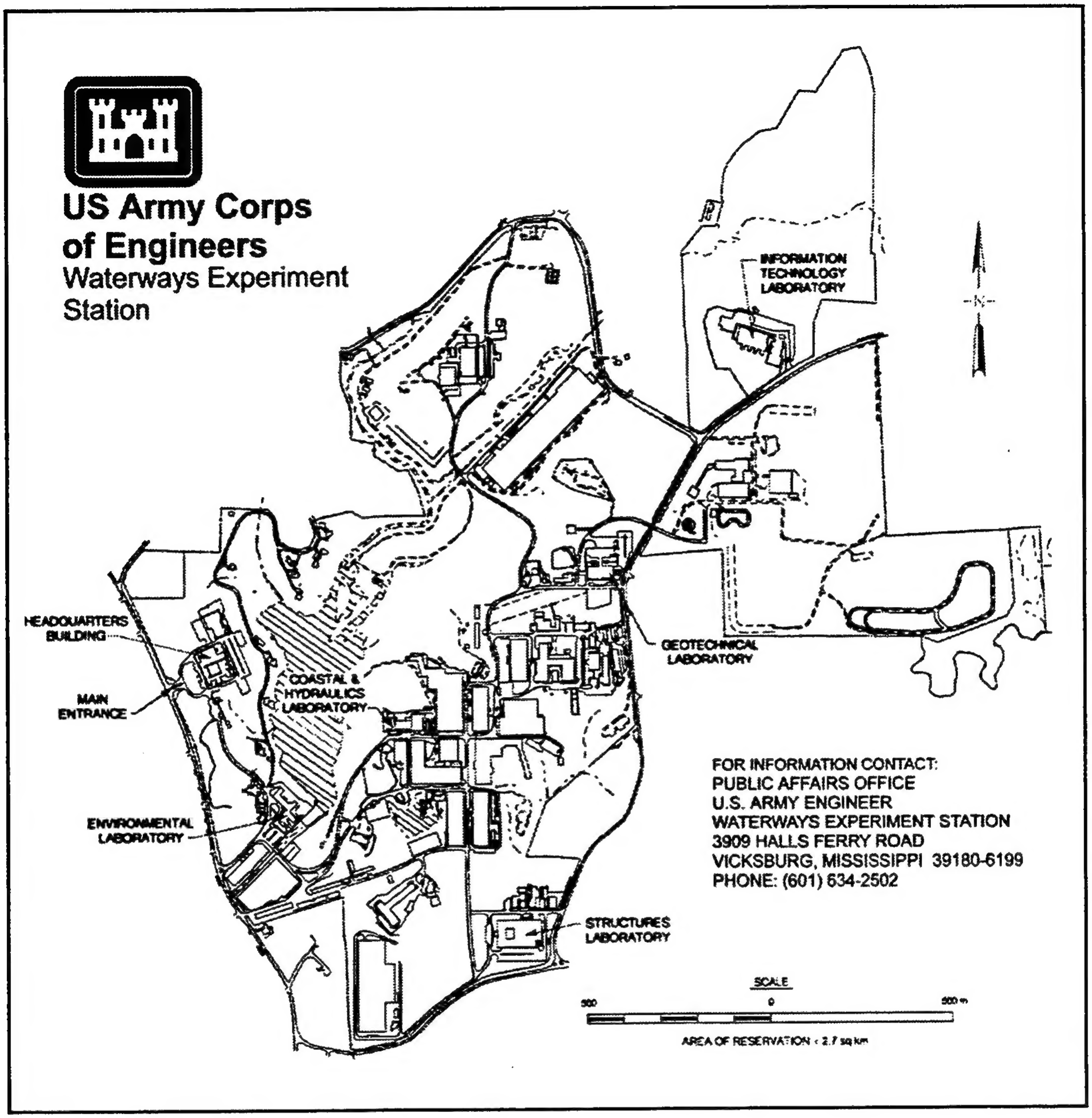

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Preface

The model investigation described herein was requested by the Deputy Chief of Staff, Logistics, Headquarters, U.S. Army Corps of Engineers, in October 1997. Tests were conducted at the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS, during the period November 1997 through January 1998.

The study was conducted by personnel of the Coastal and Hydraulics Laboratory (CHL) under the general direction of Dr. James R. Houston, Director, and Mr. Charles C. Calhoun, Jr., Assistant Director. Direct guidance was provided by Messrs. C. Eugene Chatham, Chief, Navigation and Harbors Division, CHL, and D. Donald Davidson, Chief, Coastal Structures Branch, CHL. Experiments were conducted by Mrs. Brenda J. Wright and Mr. John M. Heggins, Engineering Technicians, CHL, under the direction of Mr. R. D. Carver, Principal Investigator, CHL. This report was prepared by Mrs. Wright, Mr. Carver, and Dr. Jimmy E. Fowler.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Robin R. Cababa, EN.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
feet	0.3048	meters
inches	25.4	millimeters
kips (1000 lbs, mass)	0.002203	kilograms
knots (international)	0.5144444	meters per second
miles (U.S. nautical)	1.852	kilometers
miles (U.S. statute)	1.609347	kilometers
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic meter
square feet	0.09290304	square meters
yards	0.9144	meters

1 Introduction

Background

Force projection on a global scale requires the ability to move large quantities of personnel, equipment, and supplies, predominantly via sealift capabilities. During typical operations, waterborne logistics delivers 90 percent of all unit equipment and supplies in support of U.S. forces. The *Desert Storm/Desert Shield* and *Provide Hope Operations* are recent (wartime and peacetime) examples of U.S. military requirements to deploy and sustain forces in support of defense and national security strategies. When suitable port facilities are not available, sustainment efforts must include Logistics Over The Shore (LOTS) operations. Generally, this involves offloading military ships such as roll-on/roll- off (RO/RO) ships, auxiliary crane ships, containerships, and large tankers at sea, typically in about 50 ft of water depth. In these operations, smaller watercraft known as lighters are used to ferry cargo, equipment, and supplies to various offload points at the shore.

Floating structures such as breakwaters and causeways can be designed (wave-attenuating capabilities and mooring forces can be determined) from model studies, comparison with the performance of similar prototype structures, or with the aid of numerical models. Although previous model investigations conducted at the U.S. Army Engineer Waterways Experiment Station have provided data on the wave-attenuating capabilities of several types of floating structures, very little mooring force data is available.

The Deputy Chief of Staff, Logistics (DCSLOG), Headquarters, U.S. Army Corps of Engineers, planned a field study in the spring of 1998 to investigate loads on connector pins during Logistics-over-the-Shore operations that utilize the roll-on/roll-off discharge facility (RRDF). Given the shortage of safe mooring conditions, efforts were needed to assure a safe deployment of the prototype RRDF.

A critical component of LOTS operations, specifically those involving RO/RO vessels, is the RRDF. The RRDF is assembled from standard modular causeway sections (MCS) and provides the interface between RO/RO vessels and the lighters that transport rolling stock to shore. It is essentially a floating platform, which enables vehicles to be driven down the ship's ramp, onto the

platform and then onto lighterage. The Army wishes to increase throughput capacity of the RRDF and improve safety conditions by using an RRDF configuration that is considerably larger than has been previously used, as shown in Figure 1. In recent exercises, RRDFs have functioned quite well in relatively calm water, but during more energetic conditions, excessive platform motions in response to incident waves have severely limited or shut down RRDF operations. During energetic seas, excessive motion and water coming over the deck create safety hazards for stevedores as well as vehicle operators. In addition, concern has been expressed over the durability and capacity of the pins in elevated sea states.

Purpose of Field Experiment

The purpose of the field experiment was to determine RRDF limitations and operational capabilities in various sea states when configured as shown in Figure 1. The experiment was designed to simulate an RRDF platform loaded under a worst case scenario, which would include the weights of two M1A1 tanks, the RO/RO ramp, and lighterage ramps. MCS systems were originally designed for normal operational capability in and through sea state (SS) 2 (significant wave height, H_s, up to 1 m (3.0 ft)) and survivable through SS5 (H_s up to 3.7 m (12 ft)). The objective of this effort was to collect structural load data during sea states up to and including SS5.

The test site selected for the study was in the Chesapeake Bay, near Fort Story, Virginia. A key factor for site selection was the probability of exposure to wave conditions that would satisfy the experiment goals. Data available from existing wave gages in the Fort Story area indicated that SS2 and SS3 conditions are fairly common during the spring, and that conditions in excess of SS3 are less common but possible. A heavy weather contingency plan was developed to tow the platform to safety if it appeared that wave conditions would cause damage to the RRDF, instrumentation, or cause the RRDF mooring to fail. A failure in the mooring system could have proven catastrophic, due to the large number of commercial vessels and other structures that could have been damaged by a free-floating RRDF or by free-floating segments of the RRDF.

Purpose of Model Investigation

Design information is available for the wave-attenuating capabilities of various types of floating structures (Carver 1979, Davidson 1971, Kamel and Davidson 1968). However, very little information is available for estimating mooring forces. The primary purpose of this investigation was to determine mooring forces, due to wave action, on an RRDF that was to be deployed in a prototype test demonstration in the spring of 1998.

2 The Model

Description of Prototype

The facility under study is composed of an array of MCS's. As shown in Figure 2, individual MCS's are about 24 ft wide and 80 ft long with sloped ends, thus giving the appearance of a small barge. A five-section-wide (120-ft) by three-section-long (240-ft) facility with two single-width sections attached at opposite ends of the platform was represented in the model (Figure 1).

An existing mooring, LA-17, was chosen for representation in the model. Mooring LA-17 is a single-point mooring located about 1 mile east of the Chesapeake Bay Bridge and 1.5 miles north of Lynnhaven Inlet in a water depth of about 36 ft. Figure 3 shows the general location of the mooring. Mooring LA-17 was designed as a BB class mooring with a working holding capacity of 250,000 lb (Figure 4). Anchoring is provided by three pairs of 12,000-lb NAVMOOR anchors. The anchors are placed 120 deg apart with a 10-deg spread within each anchor pair. Anchors are connected to a 13-ft-diam buoy by 2.5-in. anchor chain and 3.5-in. riser chain. The buoy has a dry weight of 10,500 lb and a net buoyancy of 36,500 lb.

Model-Prototype Scale Relationships

Experiments were conducted at a geometrically undistorted scale of 1:42, model to prototype. Based on Froude's model law (Stevens et al. 1942) and the linear scale of 1:42, the model-prototype relations in Table 1 were derived.

The model was designed and constructed so that its center of gravity and buoyancy, draft, mass moments of inertia, and water-plane moments of inertia properly simulated those of the prototype structure. Although the prototype structure is constructed from steel, the model was necessarily constructed of marine plywood and Styrofoam. The RRDF was tested with 470-ft-long anchor chains. The 2-½ -in. prototype chain, weighing about 45 lb/lin ft, was reproduced in the model by No. 18 single-jack chain which had an approximate weight of

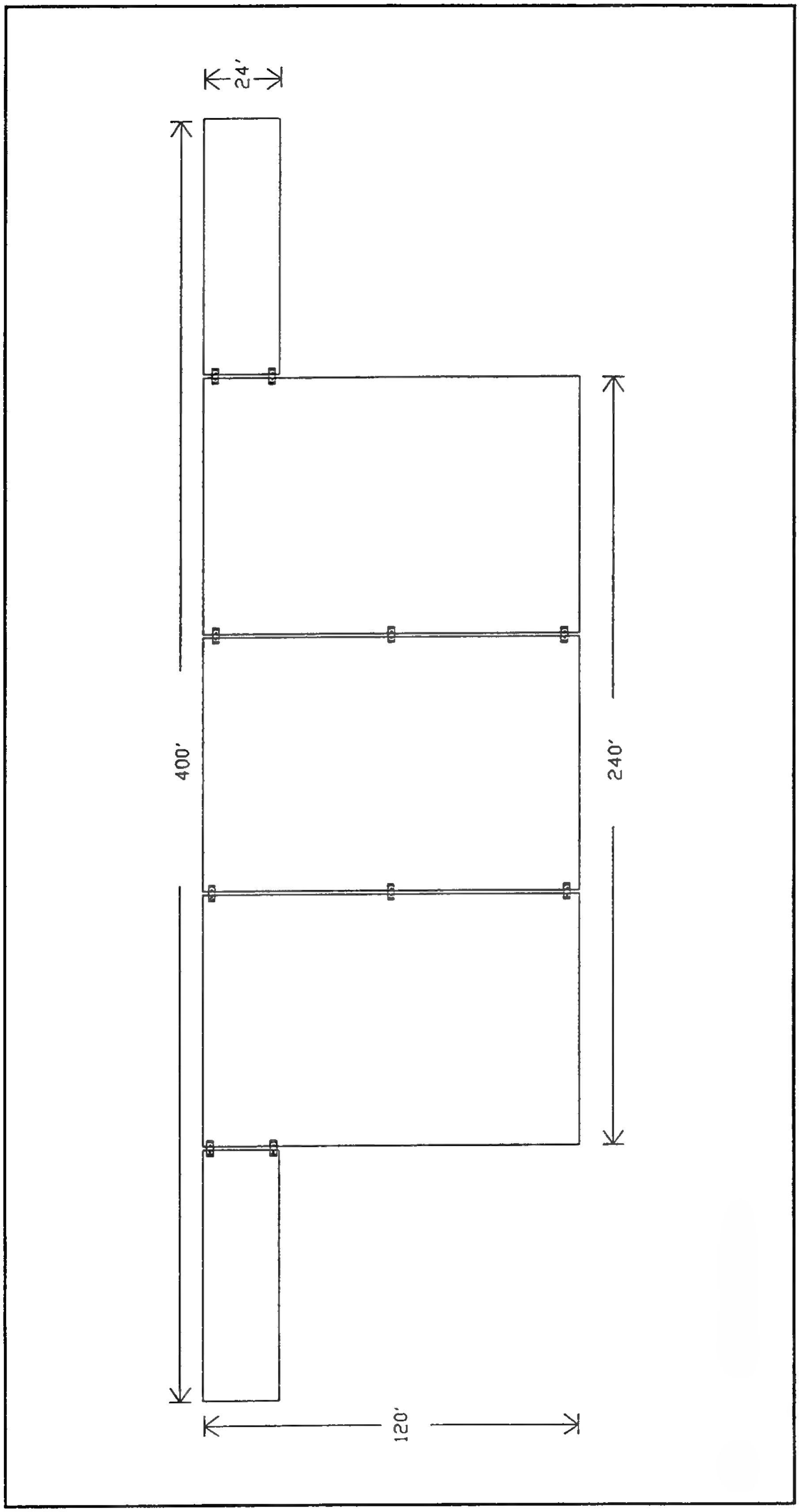
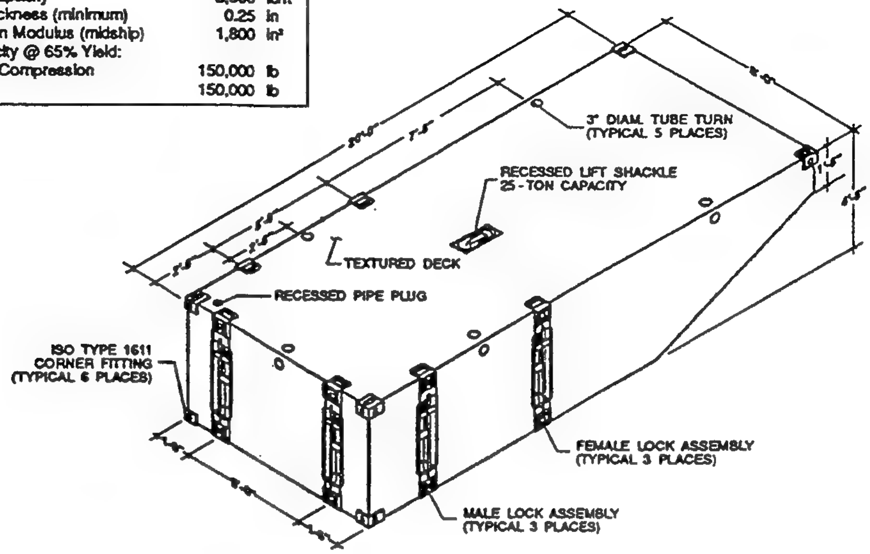
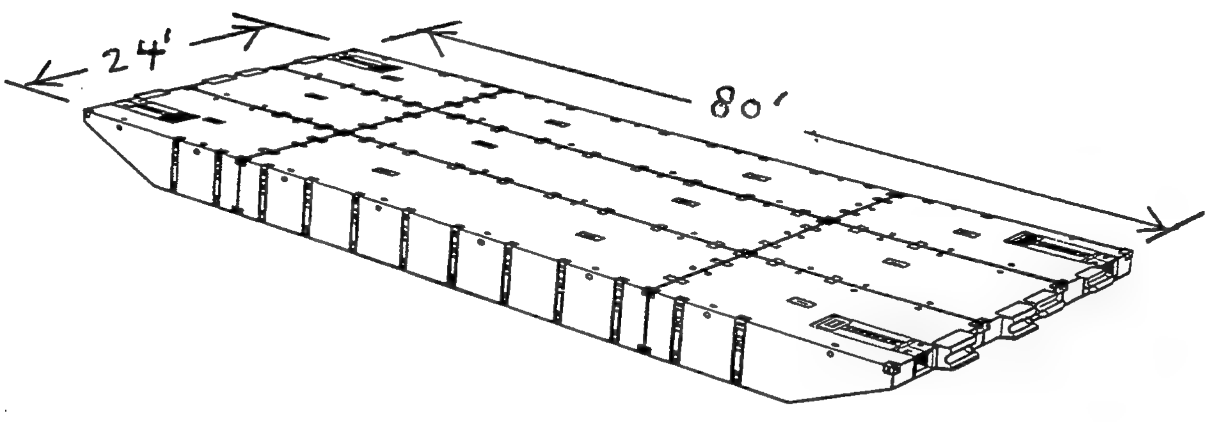


Figure 1. RRDF configuration modeled

ISOLOG End Rake Specifications		
Unit Weight	22,400	lb
No-Load Draft	14	in
Deck Bearing Capacity	5,000	lb/ft²
Bottom Bearing Capacity	3,000	lb/ft²
External Plate Thickness (minimum)	0.25	in
Transverse Section Modulus (midship)	1,800	in³
Rated Lock Capacity @ 65% Yield:		
Tension or Compression	150,000	lb
Shear	150,000	lb

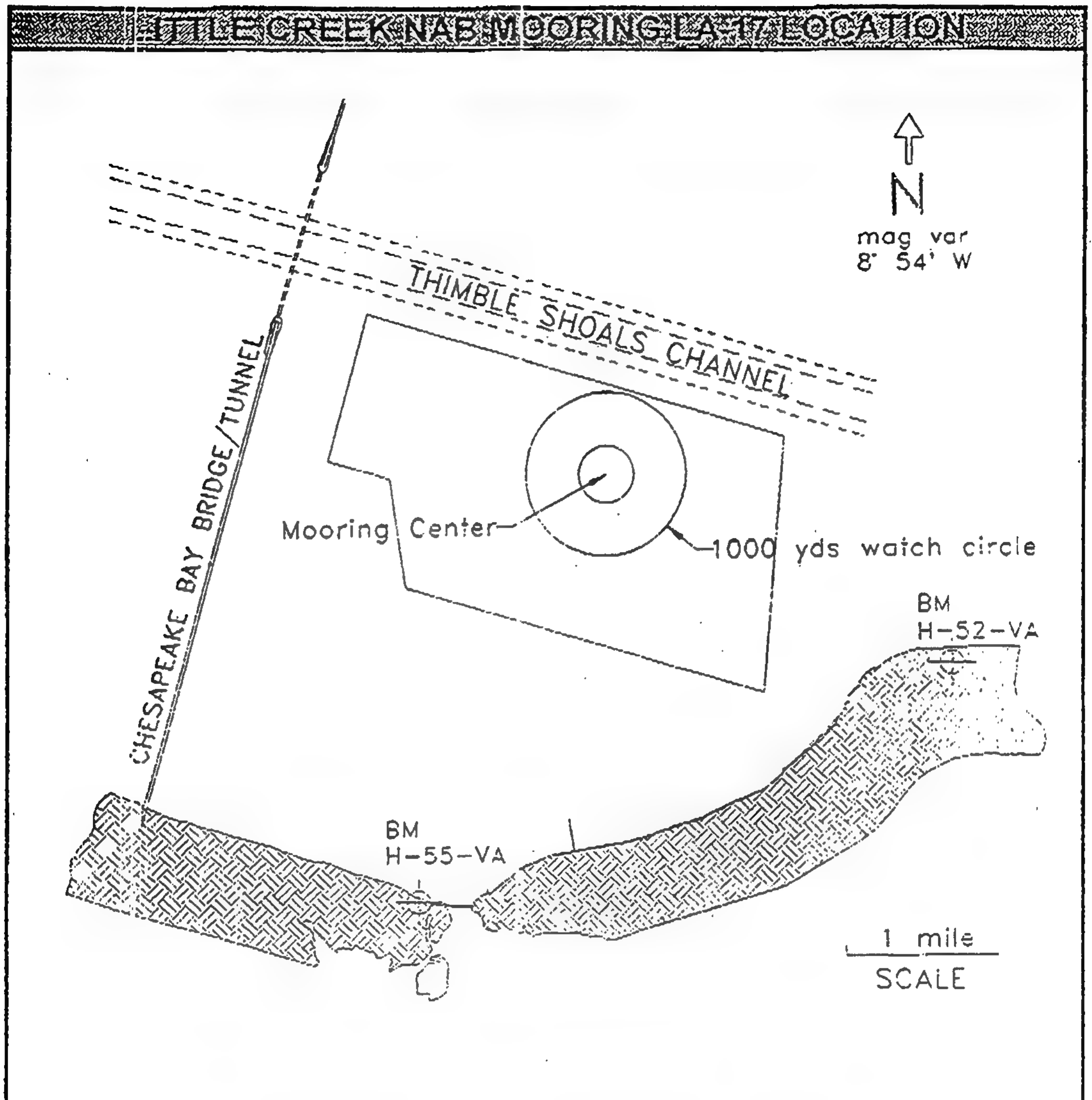


a. Raked end module



b. Fully assembled MCS

Figure 2. MCS



MOORING CENTER COORDINATE TABLE BASED ON NORTH AMERICAN DATUM 1927			
GEOGRAPHIC COORDINATES		STATE PLANE GRID COORDINATES VIRGINIA SOUTH ZONE	
NORTH LAT. (DEG. MIN. SEC.)	WEST LONG. (DEG. MIN. SEC.)	N. (FT.)	E. (FT.)
36° 53' 59.7"	076° 04' 22.7"	233602	2709156

Figure 3. Location of mooring LA-17

LITTLE CREEK NAB MOORING LA-17 USAGE CHART

Customer:	Description:
FLEET TRAINING GROUP DETACHMENT NORFOLK NAVAL AMPHIBIOUS BASE, LITTLE CREEK NORFOLK VA 23521	Single point mooring system. Class BB rated (250,000 pound working load capacity). Located in Lynnhaven Anchorage mooring site LA-17.

Designed and Installed by:	Point of Contacts: POC	Phone:	Fax:
NAVAL FACILITIES ENGINEERING SERVICE	Terry Clarke, NFESC 551	202-433-5517	202-433-5089
CENTER, EAST COAST DET	Kim Wood, NFESC 551	202-433-2341	202-433-5089
BLDG 218	CDR Stetson, FTG Det	804-464-8800	
901 M ST SE WNY	Norfolk		
WASHINGTON DC 20374-5063			

Mooring Information:		Design Information:	
Number of Moorings: 1		Max Wind:	25 knots
Buoy:	Medium foam 13 foot diameter with reflective tape, and light	Max Current:	3 knots
		Bottom:	Sand
Light:	clear color Flash rate: 4 seconds	Max Navigable Draft:	21 feet
		Water Depth: (feet below MLW) NOAA chart no. 12222	
Jewelry:	3 inch shackle & 3 inch pear link to shackle	Minimum Maintained	35
Chain:	3.5 inch Grade 3 (FM3) with anodes	Typical Water Depth	36
		Normal High Water	37
Anchors	(6) 12,000 pound NAVMOOR	See Reverse Side for Additional Information Reference NAVFAC Drawing: 6408913	

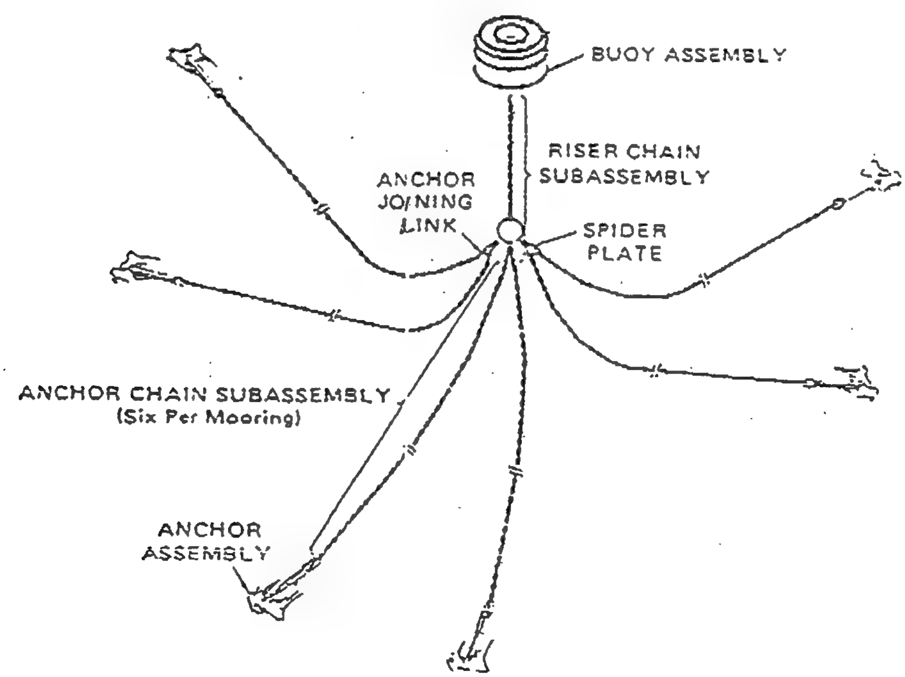


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Figure 4. Details of mooring LA-17

Table 1
Model-Prototype Relations

Characteristic	Dimension[1]	Scale Relation
Length	L	$L_r = 1:42$
Area	L^2	$A_r = L_r^2 = 1:1764$
Volume	L^3	$V_r = L_r^3 = 1:74088$
Time	T	$T_r = L_r^{1/2} = 1:6.5$
Weight	F	$W_r = L_r^3(64/62.4)$

[1] Dimensions are in terms of force (F), length (L), and time (T).

0.02 lb/lin ft. U.S. No. 3 double link chain, weighing about 0.06 lb/lin ft, was used to simulate the 3-½ -in. riser chain.

It was decided at the outset of the study that it wasn't necessary to reproduce the breaking strength of the mooring chains. Prototype chain lengths and weights were reproduced to simulate their inertial effects on the overall mooring response. Force was measured with a calibrated load link, placed in the mooring line between the buoy and RRDF.

Prototype wave directions are such that the anchor chain pairs may experience proportionally different loadings different events with all or most of the load being carried by one pair at certain times. Therefore, in order to maximize the forces in a select a pair of the anchor chains, the model morning was oriented with this pair of chains perpendicular to the wave crests and the other two pairs positioned 120 deg shoreward.

Equipment and Facilities

All experiments were conducted in an L-shaped flume. The L-shaped flume is 250 ft long, 50 and 80 ft wide at the top and bottom of the L, respectively, and 4.5 ft deep (Figure 5). Spectral waves were generated by a hydraulically activated flap-type wave machine. The model section was installed approximately 100 ft from the wave board.

Wave data were collected on electrical capacitance wave gauges. Wave signal generation and data acquisition were controlled using a DEC MicroVax III. Wave data and force analysis was accomplished using a DEC VAX 3600.

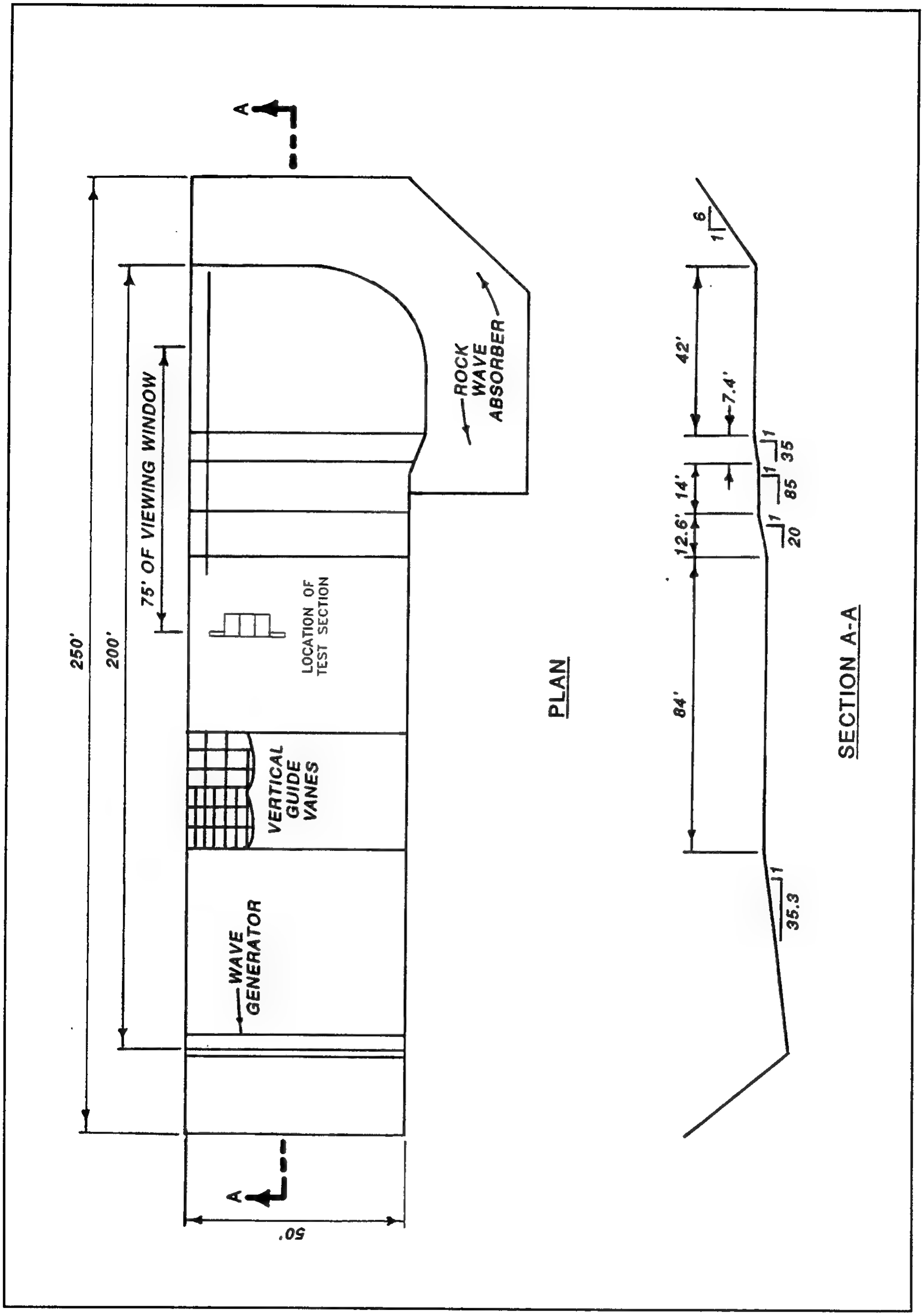

Figure 5. Layout of L-shaped flume

3 Experiments and Results

All experiments were conducted with grouped wave spectra in an effort to produce the highest peak forces obtainable in the selected water depth of 36 ft. Peak periods of the spectra were 8, 12, and 16 sec. Experiments were conducted with wave crests parallel to the long axis of the structure (0-deg wave attack) and with the structure rotated 90 deg relative to the wave crests. Forces were measured at each wave direction, as shown in Figure 6.

Initially, experiments were conducted with the discharge facility free of ramps and equipment. Results of these tests are presented in Table 2 and Figures 7-10. These data show maximum average and peak forces of 24 and 241 kips, respectively. As expected, forces decreased when the structure was rotated from 0 to 90 deg. It should be noted that all forces increase rapidly when wave heights exceed the 8- to 10-ft range. Based on model observations, the rapid force rise in this height range appears to coincide with the onset of major wave overtopping of the structure.

A second series of experiments was conducted with a 160-kip M1A1 tank placed at the geometric center of the discharge facility. Also, the loading created by both a side and stern ramp, placed as shown in Figure 11, was simulated. It was assumed that another M1A1 would be at the midpoint of each loading ramp; thus, another 80 kips was added to each ramp footprint.

Results for the loaded condition are summarized in Table 3 and Figures 12-15. These data show that the maximum average force (23 kips) was similar to the no-load condition and the maximum peak force increased to 269 kips. Generally, forces are slightly higher for the loaded condition and increase rapidly as wave heights exceed 8 to 10 ft.

A final series of experiments was conducted in which the 50-ft section of chain used to tether the RRDF to the buoy was replaced with an elastic cord that approximated the load/elongation properties of a nylon rope, 100 ft long, with a breaking strength of 200 kips. Results of experiments conducted with the larger 12- and 16-sec waves are summarized in Table 4. These data, when compared to similar conditions with the inelastic mooring, show a 50- to 60-percent reduction in the observed peak forces with the largest being reduced to 130 kips.

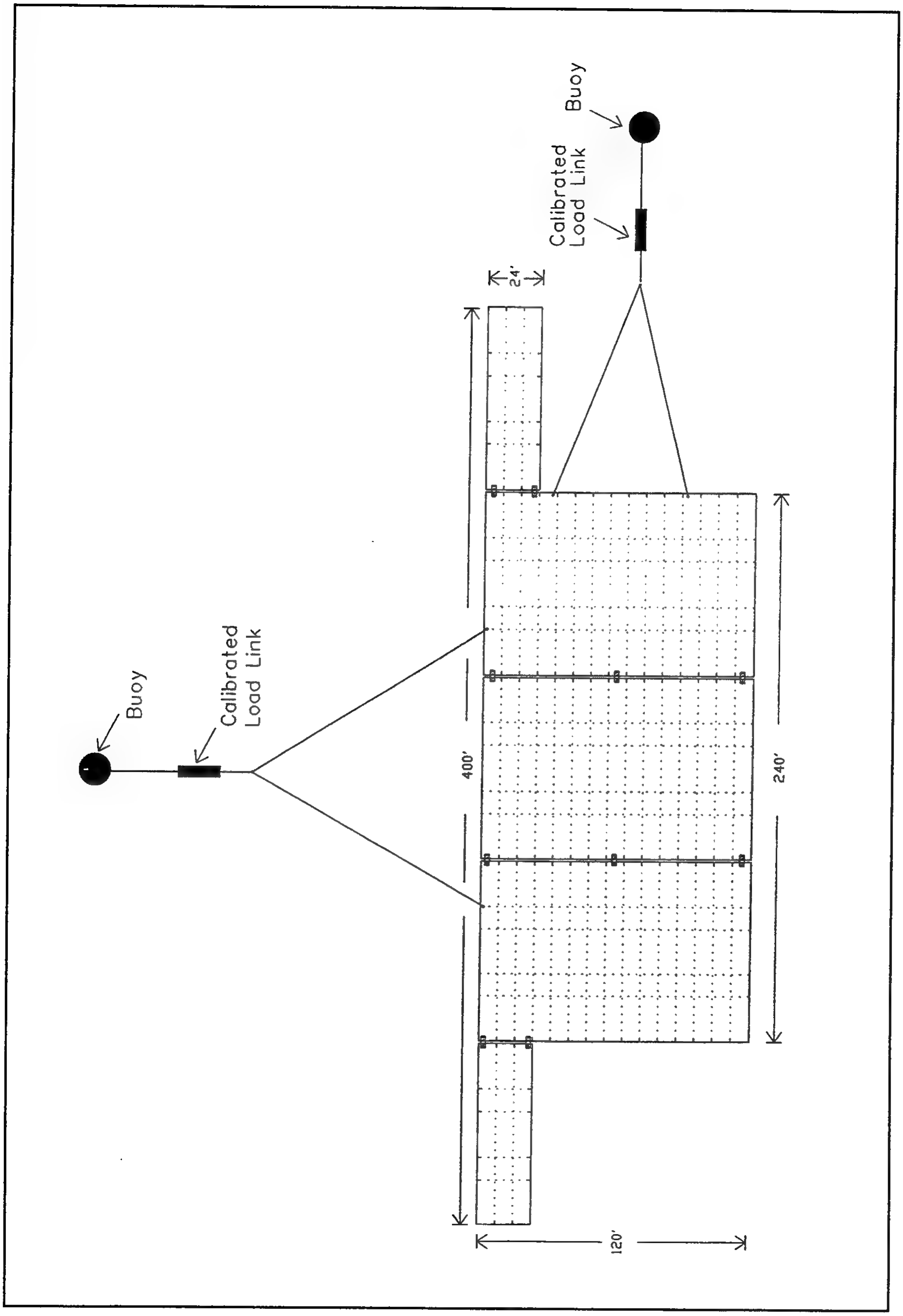

Figure 6. Locations of force measurements

Table 2
Average and Peak Mooring Forces for Unladen RRDF

T_p (sec)	H_{mo} (ft)	Avg Force (kips)	Peak Force (kips)	Angle of Wave Attack (deg)
8	3.9	1	4	0
8	7.8	2	14	0
8	9.6	4	70	0
8	11.9	14	111	0
8	13.7	19	145	0
8	14.6	24	167	0
12	3.3	1	1	0
12	6.9	1	1	0
12	8.4	1	174	0
12	10.0	9	213	0
12	11.9	13	190	0
12	13.1	23	227	0
16	3.5	1	1	0
16	5.8	1	2	0
16	7.3	1	6	0
16	8.7	2	67	0
16	10.0	6	186	0
16	11.6	12	184	0
16	12.5	15	241	0
8	3.7	1	2	90
8	7.4	2	4	90
8	9.6	6	20	90
8	11.6	12	102	90
8	13.3	16	110	90
8	14.7	16	96	90
12	4.0	1	1	90
12	8.0	1	24	90
12	8.6	1	18	90
12	10.2	3	87	90
12	11.8	6	20	90
12	13.1	12	126	90
16	2.9	1	2	90
16	5.7	2	4	90
16	7.3	1	10	90
16	9.0	2	136	90
16	10.3	5	150	90
16	12.1	10	221	90
16	12.6	11	128	90

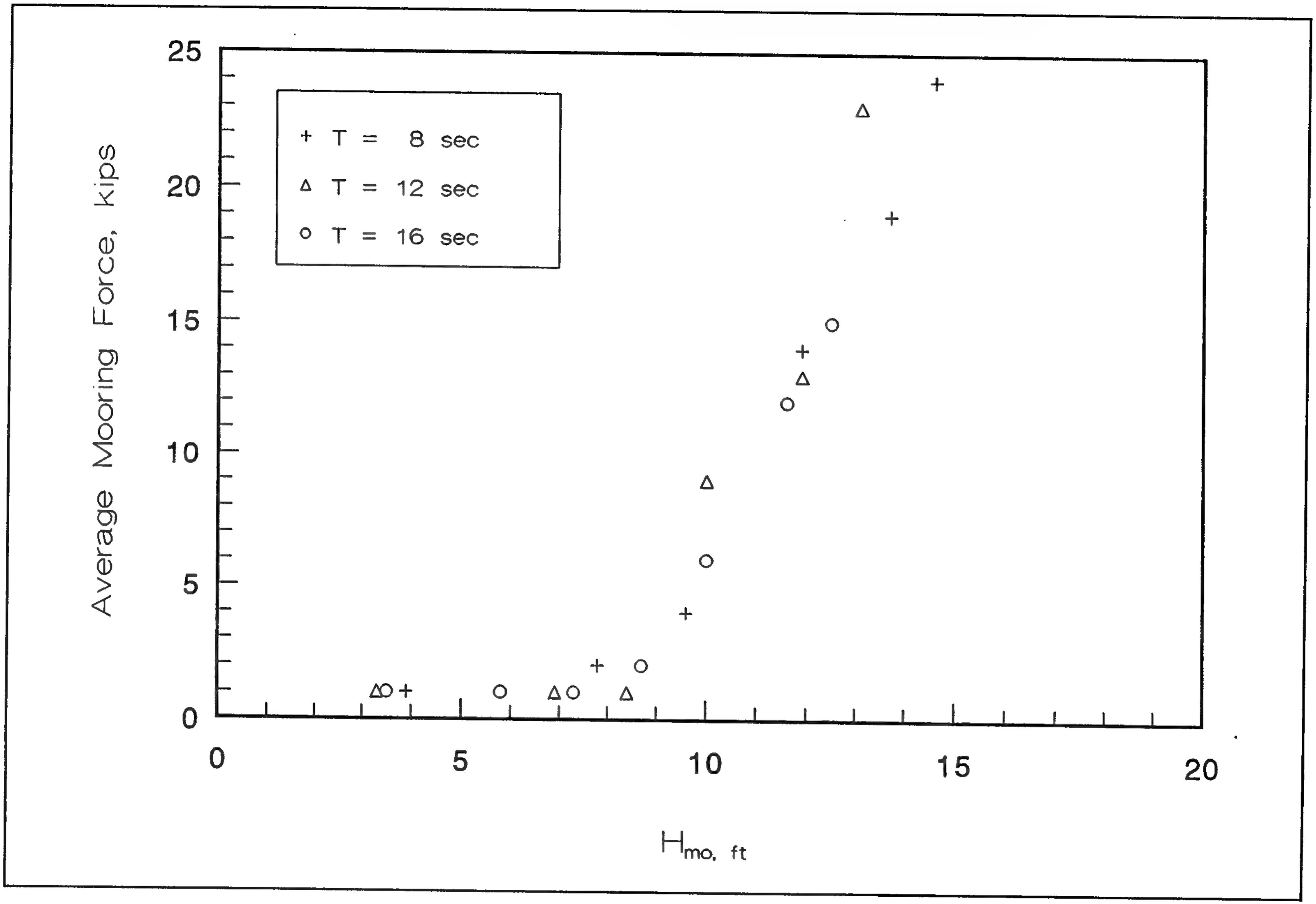

Figure 7. Average mooring force for unladen RRDF; 0-deg wave attack

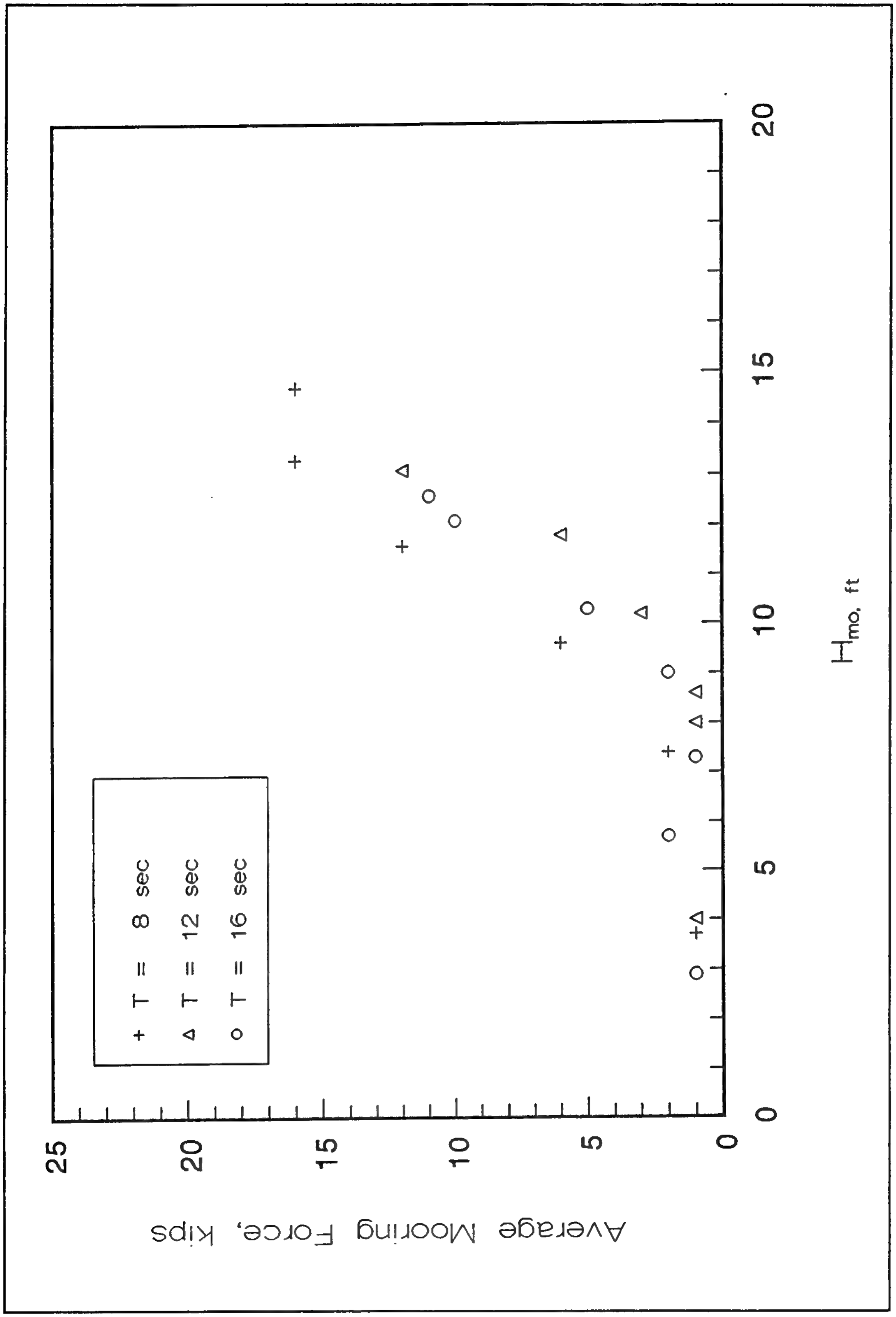

Figure 8. Average mooring force for unladen RRDF; 90-deg wave attack

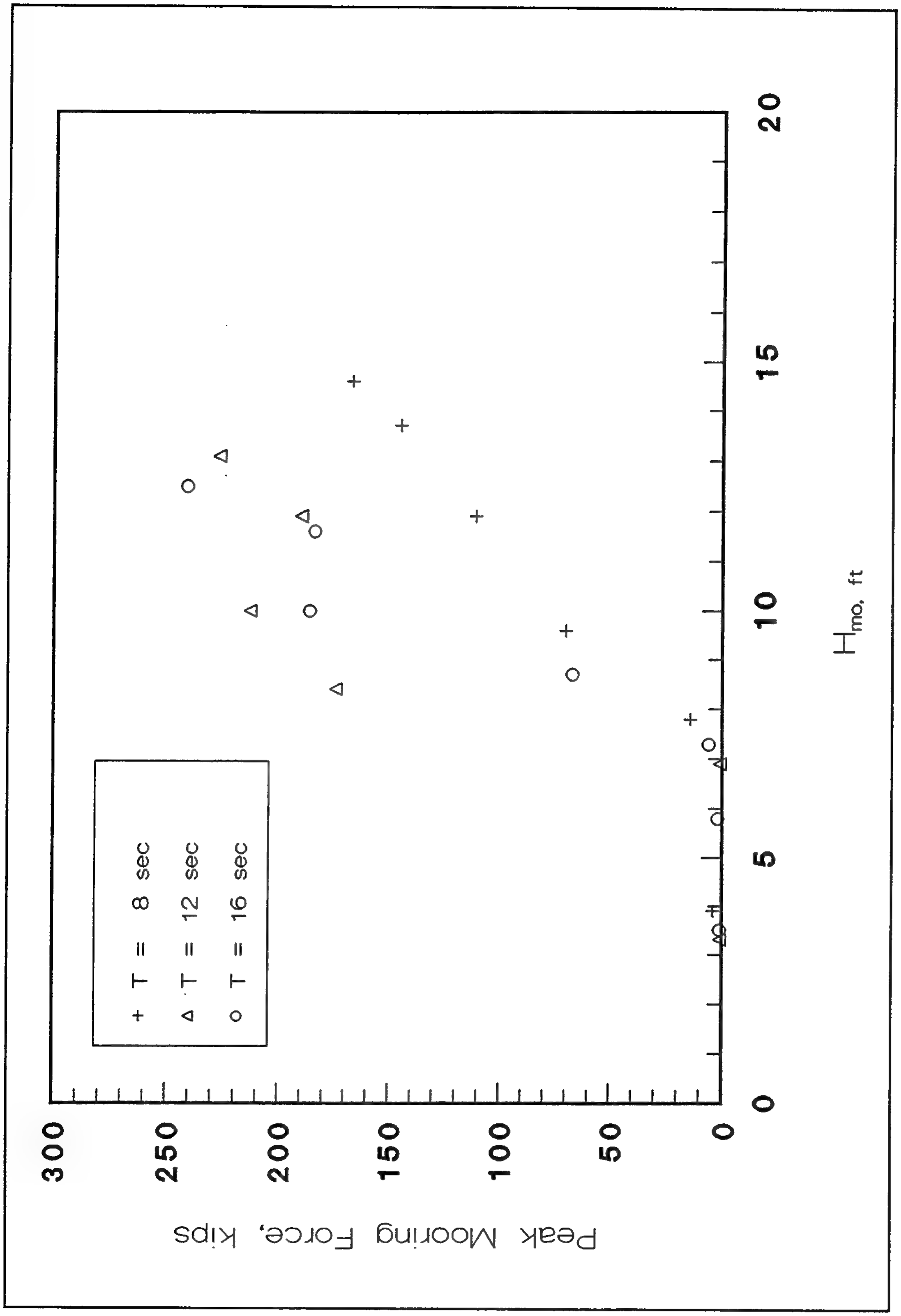

Figure 9. Peak mooring force for unladen RRDF; 0-deg wave attack

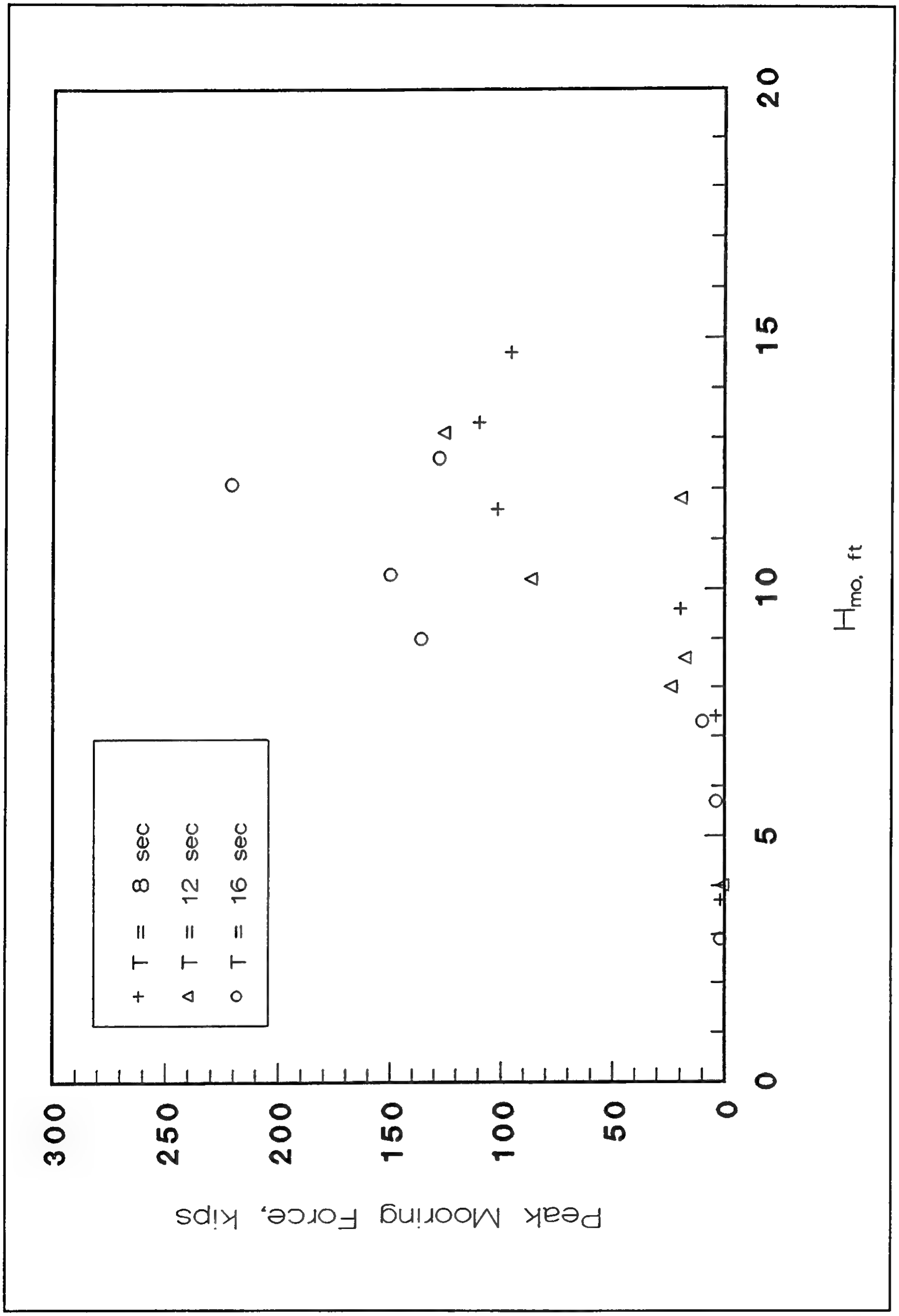

Figure 10. Peak mooring force for unladen RRDF; 90-deg wave attack

Table 3
Average and Peak Mooring Forces for Loaded RRDF

T_p (sec)	H_{mo} (ft)	Avg Force (kips)	Peak Force (kips)	Angle of Wave Attack (deg)
8	4.6	1	6	0
8	9.1	1	13	0
8	10.8	15	68	0
8	11.7	17	99	0
8	12.2	18	88	0
12	3.2	1	5	0
12	6.5	1	10	0
12	8.1	1	142	0
12	9.9	11	244	0
12	11.6	13	238	0
12	13.0	23	247	0
16	2.9	1	2	0
16	5.8	1	4	0
16	7.1	1	4	0
16	8.8	1	131	0
16	10.2	3	167	0
16	11.7	14	191	0
16	12.2	16	269	0
8	3.7	1	2	90
8	7.6	3	21	90
8	9.5	8	36	90
8	11.6	15	117	90
8	12.6	17	132	90
12	3.4	1	2	90
12	6.6	1	9	90
12	8.1	1	29	90
12	9.9	6	102	90
12	11.7	14	139	90
12	12.8	15	212	90
16	2.8	1	1	90
16	5.7	1	4	90
16	7.1	1	4	90
16	8.7	2	139	90
16	10.3	5	239	90
16	12.0	13	260	90
16	12.6	15	239	90

Table 4
Average and Peak Mooring Forces for Loaded RRDF with Elastic Mooring Line

T_p (sec)	H_{mo} (ft)	Avg Force (kips)	Peak Force (kips)	Angle of Wave Attack (deg)
12	11.6	6	79	0
12	13.0	10	118	0
16	10.0	3	113	0
16	11.8	6	113	0
12	11.6	7	82	90
12	13.0	11	104	90
16	11.0	4	119	90
16	12.5	7	130	90

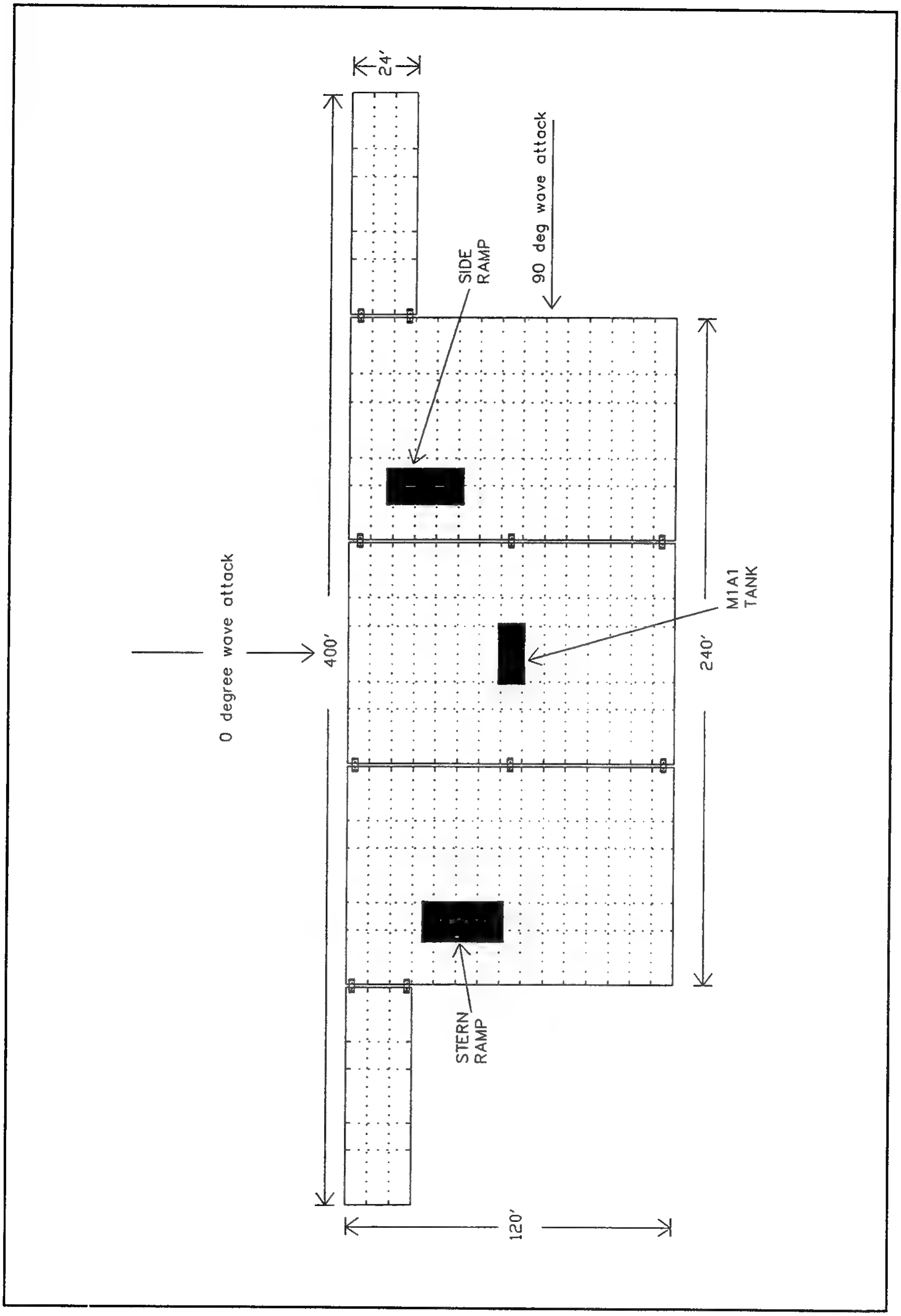

Figure 11. Location of ramps and M1A1 tank

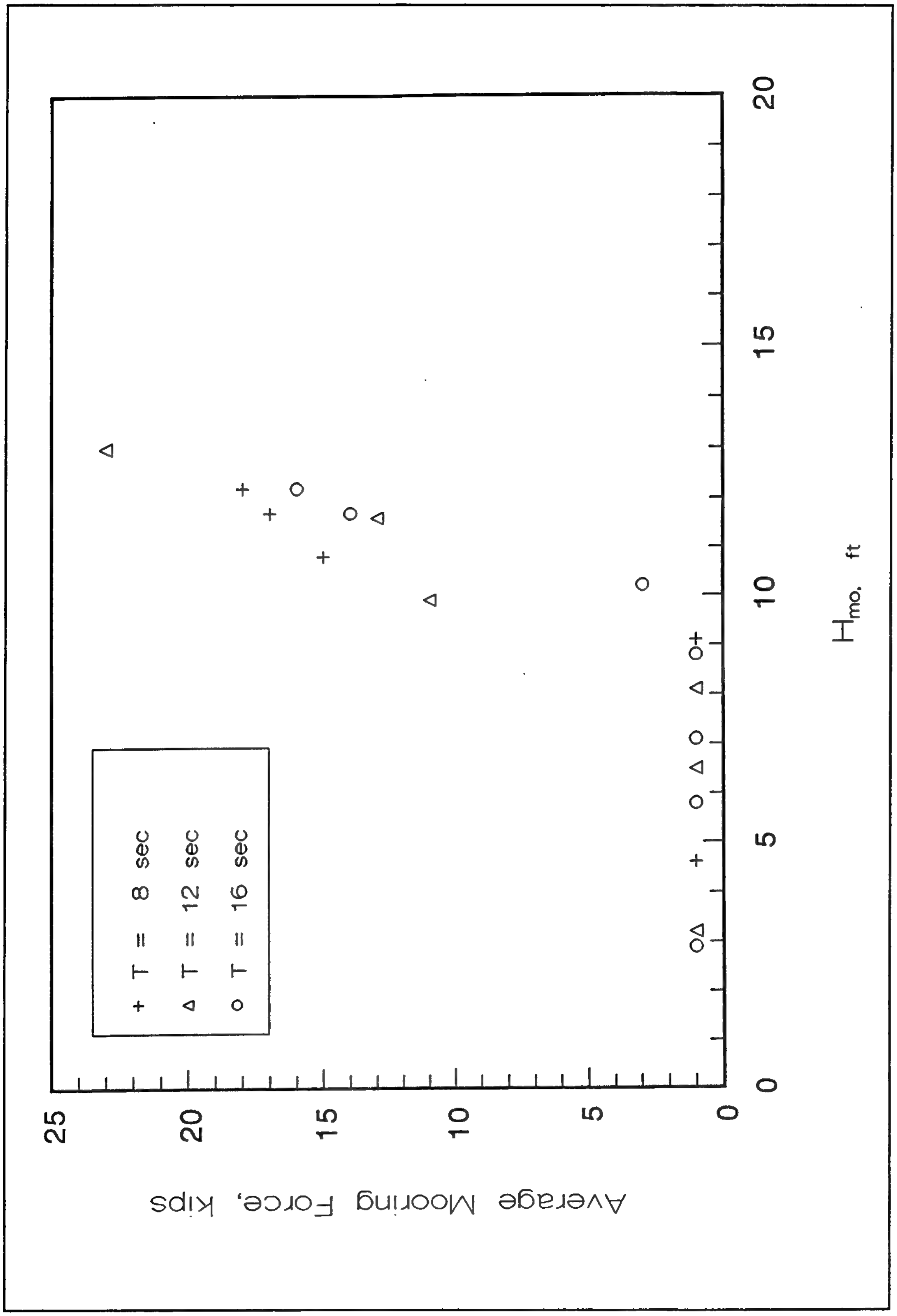

Figure 12. Average mooring force for loaded RRDF; 0-deg wave attack

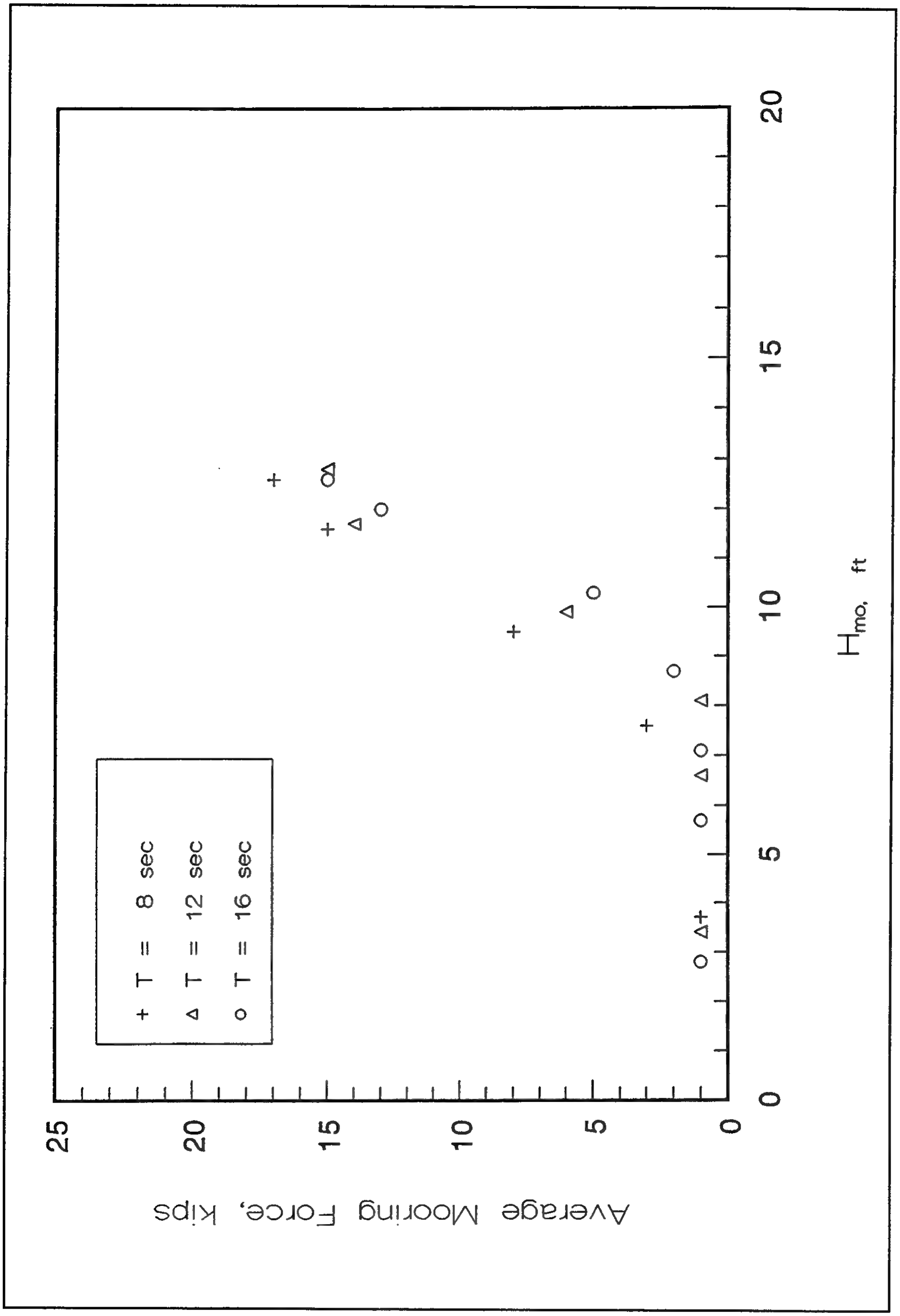

Figure 13. Average mooring force for loaded RRDF; 90-deg wave attack

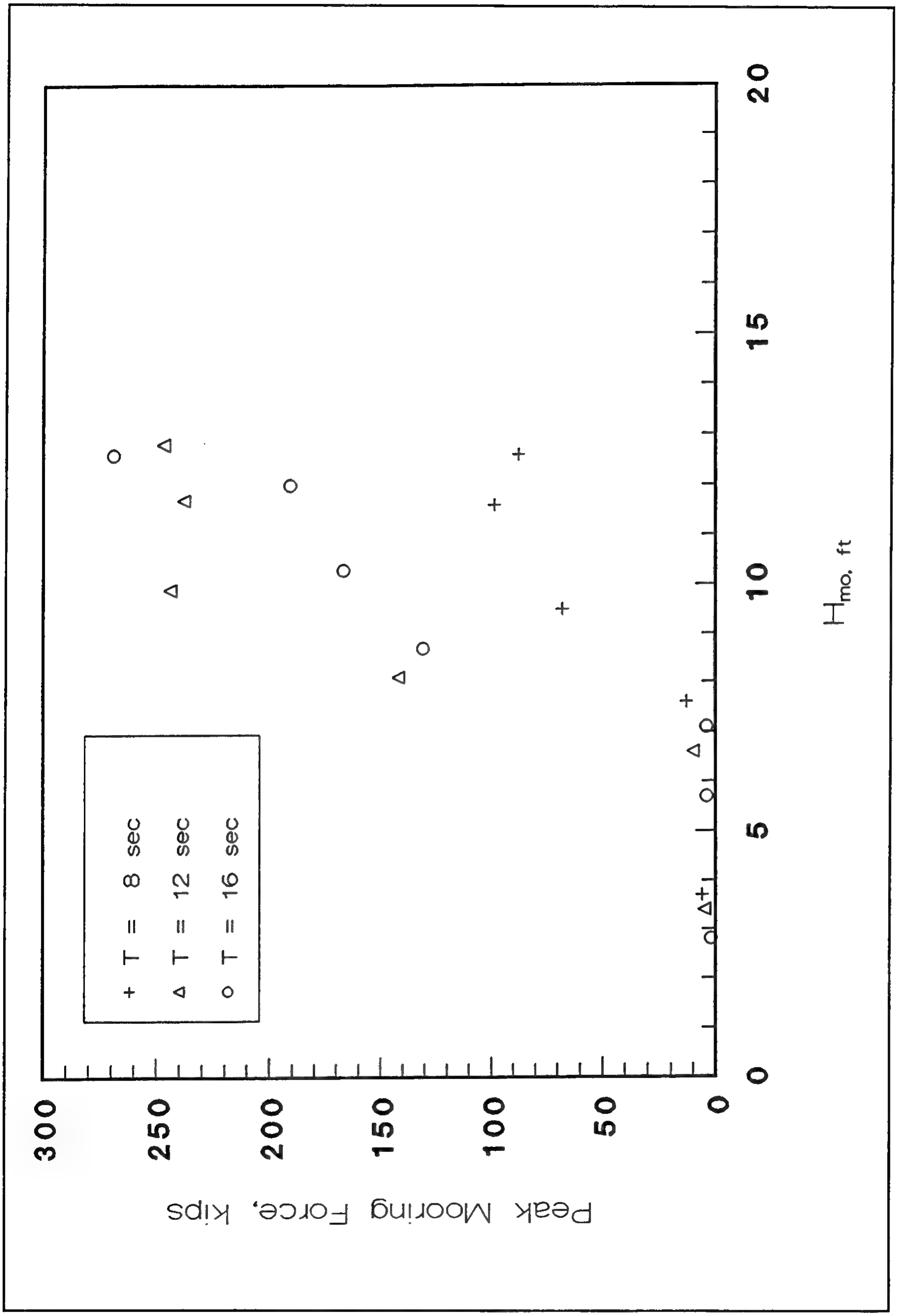

Figure 14. Peak mooring force for loaded RRDF; 0-deg wave attack

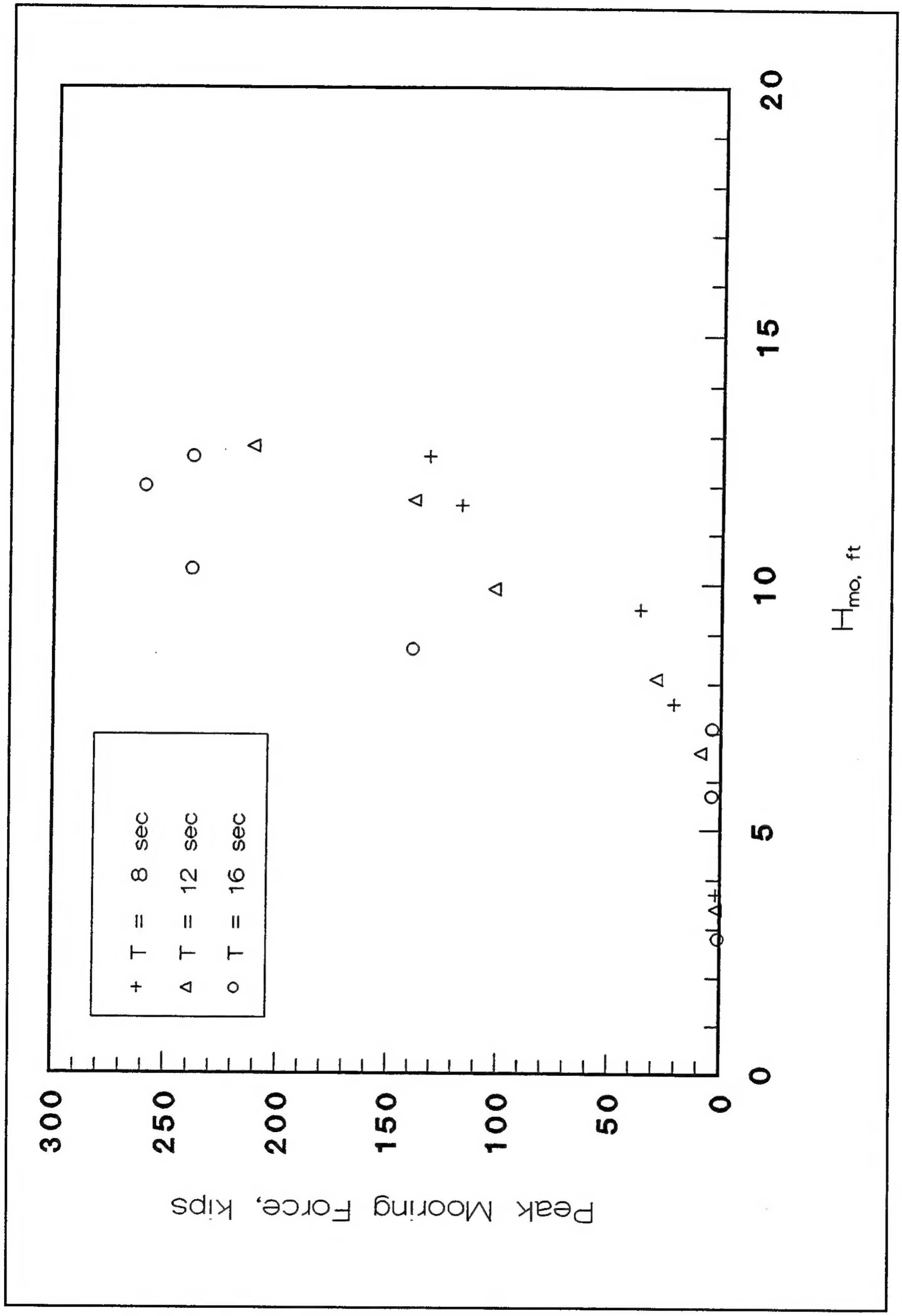

Figure 15. Peak mooring force for loaded RRDF; 90-deg wave attack

4 Discussion

For the range of conditions analyzed, the highest average mooring forces for the unloaded and loaded RRDF for the 90-deg wave direction were 16 and 17 kips, respectively. Maximum peak forces were 221 kips (unloaded) and 260 kips (loaded). For 0-deg wave attack, the highest average mooring forces, unloaded and loaded, were 24 and 23 kips, respectively. Maximum peak forces observed at 0 deg were 242 kips (unloaded) and 269 kips (loaded).

The selected BB class mooring with its working load of 250 kips should prove adequate for the range of conditions examined. When the RRDF is moored with chain, a few of the peak forces approach and even exceed 250 kips; however, these forces act for a very short interval, 0.5 sec or less.

Based on results of experiments conducted with the elastic mooring line, in which the largest peak force was 130 kips, a 3-in.-diam nylon line (breaking strength of 200 kips) should be sufficient to tether the RRDF.

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13. ABSTRACT ***(Maximum 200 words)***

This investigation was conducted to determine mooring forces, due to wave action, on a roll-on/roll-off discharge facility (RRDF) deployed in a prototype test demonstration in the spring of 1998. Experiments were conducted in an L-shaped flume using a model discharge facility. The model was tested for a range of conditions including various angles of wave attack, types of mooring lines, and wave heights. Experiments were conducted with both loaded and unloaded discharge facilities. The selected BB class mooring with its working load of 250 kips should prove adequate for the range of conditions examined. When the RRDF is moored with chain, a few of the peak forces approach or even exceed 250 kips; however, these forces act for a very short interval, 0.5 sec or less. Based on results of experiments conducted with the elastic mooring line, a 3-in.-diam nylon line should be sufficient to tether the RRDF.

14. SUBJECT TERMS

Mooring forces	Roll-on/roll-off discharge facility (RRDF)
Mooring lines	Wave action

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